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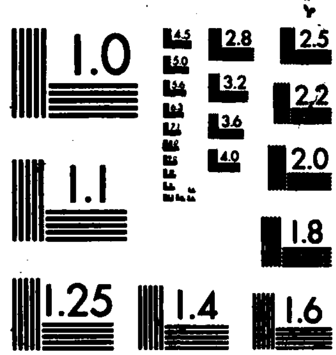

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FREQUENCY-DEPENDENT ENERGY ABSORPTION IN THE BODY AND TAIL OF THE RODENT CARCASS EXPOSED TO RADIOFREQUENCY RADIATION

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The proportion of energy absorbed by the tail of a rat carcass was determined. Male (288 g - 457 g) and female (195 g - 249 g) Sprague-Dawley rat carcasses were exposed to far-field, continuous-wave radiofrequency radiation (RFR). The carcasses were split into two mixed groups: one group was exposed to 700-MHz RFR; and the other, to 350-MHz RFR. Immediately after each exposure, the tail was severed, and the specific absorption rates (SAR) of the tail and body were determined by Dewar flask calorimetry. For example, a 195 g female exposed to 700 MHz yielded SARs of 1.26 and 3.64 mW/g (normalized to 1 mW/cm^2 incident power density) for its body and tail, respectively; the tail contributed 6.7% to the total energy absorption. For a 205 g female exposed to 350 MHz, however, the tail contributed 19.0% to the whole-body absorption. Normalized SARs of 0.40 and 4.03 mW/g per mW/cm^2 were obtained for the body and tail, respectively. Keywords: -

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FREQUENCY-DEPENDENT ENERGY ABSORPTION IN THE BODY AND TAIL OF THE RODENT CARCASS EXPOSED TO RADIOFREQUENCY RADIATION

INTRODUCTION

The absorption of radiofrequency radiation (RFR) by a biological specimen is dependent on such factors as the RFR frequency and the specimen's mass, physical dimensions, and orientation relative to the incident radiation. Typically, when speaking of the absorbed RF energy, one refers to the specific absorption rate (SAR); the SAR (expressed in watts per kilogram) is the rate of RF energy deposition in a unit mass of biological material; e.g., tissue or muscle. At the USAF School of Aerospace Medicine (USAFSAM), we undertook a study comparing the measured value of a rodent carcass' whole-body average SAR with the value predicted by the prolate spheroid model, as described by C. H. Durney et al. [1]. Since, by its nature, this prolate spheroid model did not account for appendages, we were interested in the effect a rodent's tail would have on the measured SAR vis-a-vis theory. Our SAR measurements agreed favorably with the "tailless" prolate spheroid model's predictions. We noticed, however, that the fraction of RF energy absorbed by the carcass' tail changed with frequency from 21.1% ± 4.5% at 350 MHz to 6.0% ± 2.1% at 700 MHz. Also, this phenomenon appeared to be independent of carcass mass -- at least, in the mass range considered here.

For this study, 38 male (288-457 g) and 19 female (195-249 g) Sprague-Dawley rats were placed in two mixed groups. In the first group, 27 male (294-457 g) and 10 female (195-249 g) rats were euthanized and then exposed to 700-MHz continuous-wave (CW) RFR. The second group consisted of 11 male (288-422 g) and 9 female (205-246 g) euthanized rats that were exposed to 350-MHz CW RFR. The RF energies absorbed by the body and tail of the respective carcass were measured by Dewar flask calorimetry.

METHODS AND MATERIALS

At least 18 h pre-exposure, the test subject was euthanized, weighed, and catheterized with a Bowman-type thermistor temperature probe [2] inserted 10 cm into the rectum. To reduce the rate of thermal exchange between the subject and its environment, the carcass was wrapped in a commercially available household plastic wrap, 1.5 mil thick. The carcass was next placed in a cardboard "shoebox" (46 cm x 13 cm x 10 cm) filled with small (approx. 1 mm diam.) Styrofoam beads that provided an insulating blanket, at least 2 cm thick, about the specimen. The shoebox was then placed in a room in which the ambient temperature was maintained to within ±0.5°C of the exposure chamber air temperature.

Immediately before irradiation, the carcass' rectal temperature was recorded at 12-s intervals by means of a BSD-200 electrothermia monitor system; an average of the most recent ten consecutive readings of the rectal thermistor probe was taken as the average whole-body pre-exposure temperature of the animal, for calorimetric purposes [3]. The rectal probe was removed

from the carcass, and the shoebox was placed in an RF anechoic chamber (Emerson and Cuming, Inc., SN 966) for exposure. All exposures were of 5-min duration, and were conducted with the animal's trunk centered at 1 m from the vertex, and along the boresight, of a 90° corner reflector antenna (Fig. 1). This location was in the antenna's far-field radiation zone for both frequencies. Kraus [4] has described the theory and characteristics of the corner reflector antenna; our antenna consisted of a half-wavelength feed dipole, 0.3 wavelengths from the reflector vertex. For each exposure, the shoebox was placed so that the long axis of the carcass was aligned parallel to the incident electric field; this arrangement is referred to as the "E orientation."

An RF power generator (Microwave Cavity Laboratories [MCL], model 1502), with a 500- to 1000-MHz plug-in (MCL model 6050), was the source of the 700-MHz RFR. For the exposures, this RF signal was amplified to preferred power levels by an RF power amplifier (MCL model 10110B) with a 600- to 1000-MHz plug-in (MCL model 11104). For the 350-MHz exposures, the driver was an RF power generator (MCL model 15222), with a 200- to 500-MHz plug-in (MCL model 6049). The 350-MHz source signal was amplified by an RF power amplifier (MCL model 10110), with a 200- to 400-MHz plug-in (MCL model 11044). Refer to Figures 2 and 3 for the 350- and 700-MHz exposure arrangements.

The amplified RF signal was transmitted to the corner reflector antenna by RG 318/U coaxial waveguide; the impedance mismatch between the antenna and the waveguide was reduced by a double-stub tuner inserted into the line. A directional coupler (Connecticut Microwave Corporation, model 460005), with coupling ratios of 50 dB and 40 dB for the forward and reverse directions, respectively, was used to sample the incident and reflected RF powers in the waveguide. Each power component was detected by a bolometer (Hewlett-Packard [HP] model 478A), and measured by a power meter (HP model 432B); in addition, for the 700-MHz exposures, the forward and reflected powers were recorded by a chart recorder (Gould, Inc., model 2600S). The 5-min exposure duration was measured with a universal timer (Dimco-Gray Company, Graylab, type 171) that was graduated in seconds.

After the exposure, the shoebox was removed from the anechoic chamber, and carried 12 ft into the other temperature-controlled room. The rat carcass was removed, the tail was severed and placed in a Dewar flask calorimeter containing 100 g of water, and the body was placed in another calorimeter containing 500 g of water. Each calorimeter contained a thermistor probe which, when used with the BSD-200 system, allowed us to monitor the internal flask temperature. A modified variable speed water-bath shaker (Research) Specialties Co.) was used to gently agitate the body calorimeter in order to "smooth out" the temperature vs. time plots obtained on the BSD-200. The tail calorimeter was manually agitated periodically. An average ambient temperature, as measured with two thermistor probes and displayed on the BSD-200, was maintained to within $\pm 0.5^{\circ}C$ of the average body calorimeter temperature. The tail and body were removed when they had come to temperature equilibrium within their flasks. The rat body was discarded; however, the tail was allowed to air dry, for approximately 6 h, before being weighed. The carcass' exposure temperature was determined from the heat balance equation:

EDITOR'S NOTE: For the convenience of the reader, Figures 1, 2, and 3 have been placed at the close of this report.

$$Tm = Tf + (MwCw + ZD)(Tf - To)/(Cm \times Mm), \qquad (1)$$

in which

Tf = final calorimeter and carcass temperature (°C);

To = initial calorimeter water temperature (°C);

Mw = mass of the calorimeter water (kg);

Cw = specific heat of water (assuming STP), 4,185 J/kg-°K;

Mm = mass of the specimen (kg);

Cm = average specific heat of the specimen, 3,448 J/kg-°K; and

ZD = heat capacity of the calorimeter, 110,484 J/kg-°K.

The SAR is determined from the relation [3]:

$$SAR(W/kg) = Cm \times (Tm - Trectal) / \Delta t,$$

in which

Tm = calorimetrically determined average exposure temperature (°C);

Trectal = average carcass pre-exposure rectal temperature (°C); and

Δt = exposure durations(s).

RESULTS

Listed in Table 1 are the calorimetrically determined SARs for the rodents exposed to 700-MHz CW RFR; these values are normalized to the incident RF power density. Likewise, the normalized SARs for the 350-MHz exposures are given in Table 2.

DISCUSSION

D'Andrea et al. [5] have measured the whole-body SARs for euthanized male Long-Evans rats (225-300 g) exposed to CW, linearly polarized 360-, 700-, 915-, and 2450-MHz RFR. SARs of approximately 0.6 and 0.2 mW/g (per 1 mW/cm^2 incident power density), were measured for the 700- and 360-MHz exposures, respectively. In the mass range of 223-301 g, however, we measured average, normalized whole-body SARs of 1.1 ± 0.2 (S.D.) mW/g and 0.4 ± 0.1 (S.D.) mW/g for 700- and 350-MHz exposures, respectively. This divergence from the D'Andrea data is probably due to relative differences in the carcass' heat loss during exposure, and to differences in the calorimetric techniques employed. D'Andrea's rats were exposed, for 3 min, to power densities of 90-200 mW/cm^2; during this time, the carcass lost heat by conduction and radiation, in a process that depressed the measured SAR. Although our exposures were of approximately twice the duration, our rodent carcasses remained thermally insulated by the RF transparent Styrofoam beads. D'Andrea's group used a

TABLE 1. NORMALIZED SPECIFIC ABSORPTION RATES (SARs) FOR EUTHANIZED RATS EXPOSED TO 700-MHz CW RFR

Mass (g)		Length		Sex	Normalized SAR (mW/g)		Ratio of tail length to total length	Percentage of total energy absorbed	
Body	Tail	Body	Tail	(M/F)	Measured	Theoretical		Body	Tail
190.3	4.7	20.5	16.5	F	1.31	1.21	0.45	93.3	6.7
200.6	4.9	20.5	16.5	F	1.20	1.14	0.45	93.0	7.0
206.8	4.7	21.0	16.5	F	1.31	1.13	0.44	92.9	7.1
207.7	4.6	21.5	16.5	F	1.28	1.14	0.43	95.3	4.7
218.0	5.3	21.3	17.5	F	1.30	1.08	0.45	94.0	6.0
223.1	5.5	21.5	17.7	F	1.23	1.06	0.45	95.1	4.9
234.1	4.9	22.5	17.5	F	1.13	1.03	0.44	95.2	4.8
236.7	5.6	22.5	17.2	F	1.21	1.01	0.43	91.7	8.3
241.6	5.3	22.0	16.6	F	1.20	0.99	0.43	95.1	4.9
242.7	5.8	22.3	17.4	F	1.25	0.99	0.44	90.9	9.1
287.5	6.0	22.7	18.0	M	0.68	0.85	0.44	88.6	11.4
300.5	6.0	22.5	17.5	M	0.85	0.81	0.44	95.5	4.5
302.2	6.6	23.0	18.0	M	0.70	0.81	0.44	92.7	7.3
304.8	5.7	23.2	18.0	M	0.71	0.80	0.44	93.4	6.6
309.5	6.5	24.5	19.5	M	0.75	0.78	0.44	95.1	4.9
312.6	6.2	22.5	18.5	M	0.76	0.78	0.45	95.5	4.5
315.1	6.3	23.0	18.5	M	0.76	0.78	0.45	93.3	6.7
334.8	6.8	23.0	19.0	M	0.90	0.74	0.45	94.6	5.4
335.7	6.9	23.5	19.0	M	0.90	0.73	0.45	92.3	7.7
336.1	6.5	23.3	18.6	M	0.55	0.73	0.44	93.5	6.5
341.9	7.3	24.0	19.0	M	0.81	0.72	0.44	93.0	7.0
342.2	7.6	24.5	19.5	M	0.69	0.71	0.44	90.7	9.3
346.0	7.1	24.0	19.0	M	0.62	0.71	0.44	93.2	6.8
346.7	6.8	24.0	19.0	M	0.63	0.71	0.44	90.4	9.6
358.4	7.0	23.5	18.5	M	0.70	0.69	0.44	93.5	6.5
362.1	7.3	25.0	19.5	M	0.53	0.67	0.44	92.9	7.1
363.1	7.6	23.5	19.0	M	0.58	0.68	0.45	97.4	2.6
368.3	7.5	25.0	20.0	M	0.56	0.66	0.44	98.6	1.4
370.1	7.9	22.5	20.0	M	0.58	0.67	0.47	93.9	6.7
375.4	7.1	23.5	19.0	M	0.50	0.66	0.45	94.4	5.6
379.6	7.8	25.0	19.5	M	0.51	0.65	0.44	97.4	2.6
382.9	8.2	25.0	20.5	M	0.65	0.64	0.45	94.7	5.3
384.9	7.8	25.5	20.0	M	0.73	0.63	0.44	98.4	1.6
396.2	8.9	25.0	20.5	M	0.61	0.62	0.45	92.6	7.4
399.5	8.0	24.0	20.0	M	0.47	0.62	0.46	95.9	4.1
428.0	8.3	25.5	20.2	M	0.49	0.58	0.44	94.3	5.7
448.1	8.7	26.0	20.0	M	0.55	0.55	0.44	95.3	4.7
						Average:	0.44	94.0%	6.0%
							±0.01	±2.1%	±2.1%

TABLE 2. NORMALIZED SPECIFIC ABSORPTION RATES (SARs) FOR EUTHANIZED RATS EXPOSED TO 350-MHz CW RFR

Mass (g) Body	Mass (g) Tail	Length Body	Length Tail	Sex (M/F)	Normalized SAR (mW/g) Measured	Normalized SAR (mW/g) Theoretical	Ratio of tail length to total length	Percentage of total energy absorbed Body	Percentage of total energy absorbed Tail
199.9	4.6	20.2	16.5	F	0.48	0.37	0.45	81.0	19.0
209.0	5.1	21.5	16.5	F	0.50	0.45	0.43	81.6	18.4
211.9	5.3	22.5	17.5	F	0.60	0.53	0.44	86.4	13.6
223.2	5.5	21.0	18.0	F	0.44	0.39	0.46	79.1	20.9
223.9	5.4	22.0	17.5	F	0.34	0.46	0.44	81.7	18.3
230.0	6.1	22.0	18.0	F	0.45	0.45	0.45	65.3	34.7
232.3	5.6	22.5	16.5	F	0.33	0.49	0.42	79.1	20.9
232.1	6.2	22.0	17.5	F	0.47	0.45	0.44	79.2	20.8
241.3	5.0	22.0	17.8	F	0.43	0.44	0.45	79.3	20.7
282.1	5.7	23.0	18.0	M	0.38	0.46	0.44	79.7	20.3
343.8	6.7	24.0	19.0	M	0.46	0.47	0.44	78.5	21.5
351.1	6.8	25.0	19.0	M	0.47	0.54	0.43	82.7	17.3
352.7	6.6	24.0	19.0	M	0.46	0.46	0.44	70.4	29.6
355.0	6.8	24.5	19.0	M	0.43	0.49	0.44	81.9	18.1
355.4	7.1	25.0	19.0	M	0.47	0.53	0.43	79.6	20.4
372.0	7.3	24.5	20.0	M	0.41	0.47	0.45	78.6	21.4
376.9	6.3	25.0	19.0	M	0.49	0.51	0.43	82.3	17.7
394.8	7.5	25.0	19.5	M	0.41	0.49	0.44	75.7	24.3
395.0	7.5	24.5	19.5	M	0.41	0.46	0.44	79.0	21.0
414.4	7.9	25.5	19.5	M	0.45	0.51	0.43	77.1	22.9
						Average:	0.44	78.9	21.1
							±0.01	±4.5	∓4.5

twin-well calorimeter to determine the RF energy deposited in a rat, by comparing the calorimeter thermopile voltage-time curve for the radiated carcass to similar curves obtained from adding a known amount of energy to the calorimeter. In his paper, D'Andrea did not discuss the accuracy of this calorimetric interpolation.

Our measured whole-body rat SARs compare well with the prolate spheroid theoretical model. The average percent error for the 700-MHz exposures was 0.7%±15.8%; whereas, for the 350-MHz portion, the average percent error was -5.3%±14.4%. We also noticed that the amount of energy deposited among the bodies and tails of the carcasses was frequency dependent, yet independent of mass (at least, between 195 and 450 g). According to Tables 1 and 2, at 700 MHz the tail accounted for 6% of the total energy absorbed; however, at one-half that frequency, the tail absorption rose to 21%.

REFERENCES

1. Durney, C. H., et al. Radiofrequency radiation dosimetry handbook, 3rd ed. USAFSAM-TR-80-32, Aug 1980.

2. Bowman, R. R. A probe for measuring temperature in radiofrequency heated material. IEEE Trans Microwave Theory Tech MTT-24:43-45 (1976).

3. Padilla, J. M., and R.R. Bixby. Using Dewar-flask calorimetry and rectal temperatures to determine the specific absorption rates of small rodents. USAFSAM-TP-86-3, Aug 1986.

4. Kraus, J. D. Antennas. New York: McGraw-Hill, 1950.

5. D'Andrea, J.A., et al. Microwave radiation absorption in the rat: frequency-dependent SAR distribution in body and tail. Bioelectromagnetics 6:199-206 (1985).

F I G U R E S 1, 2, and 3

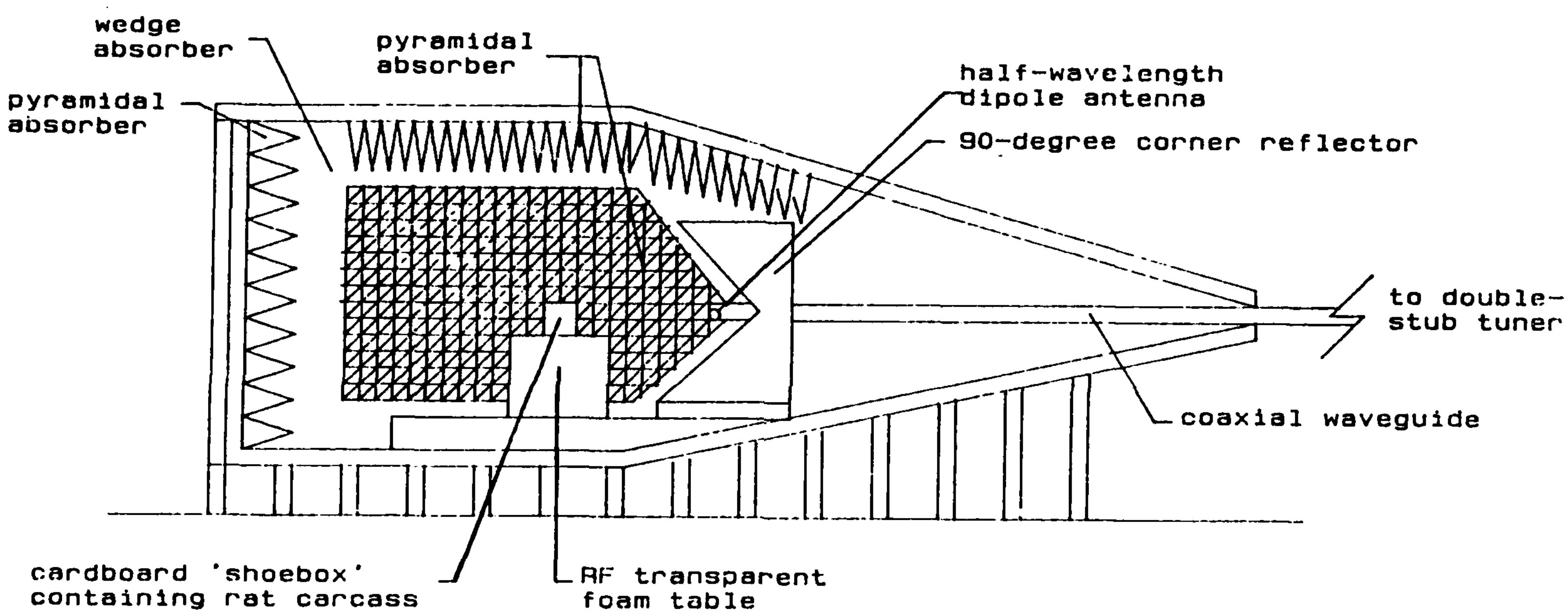

Figure 1. The 200-MHz to 30-GHz Eccosorb anechoic chamber used in the 350- and 700-MHz CW RFR exposures of rat carcasses.

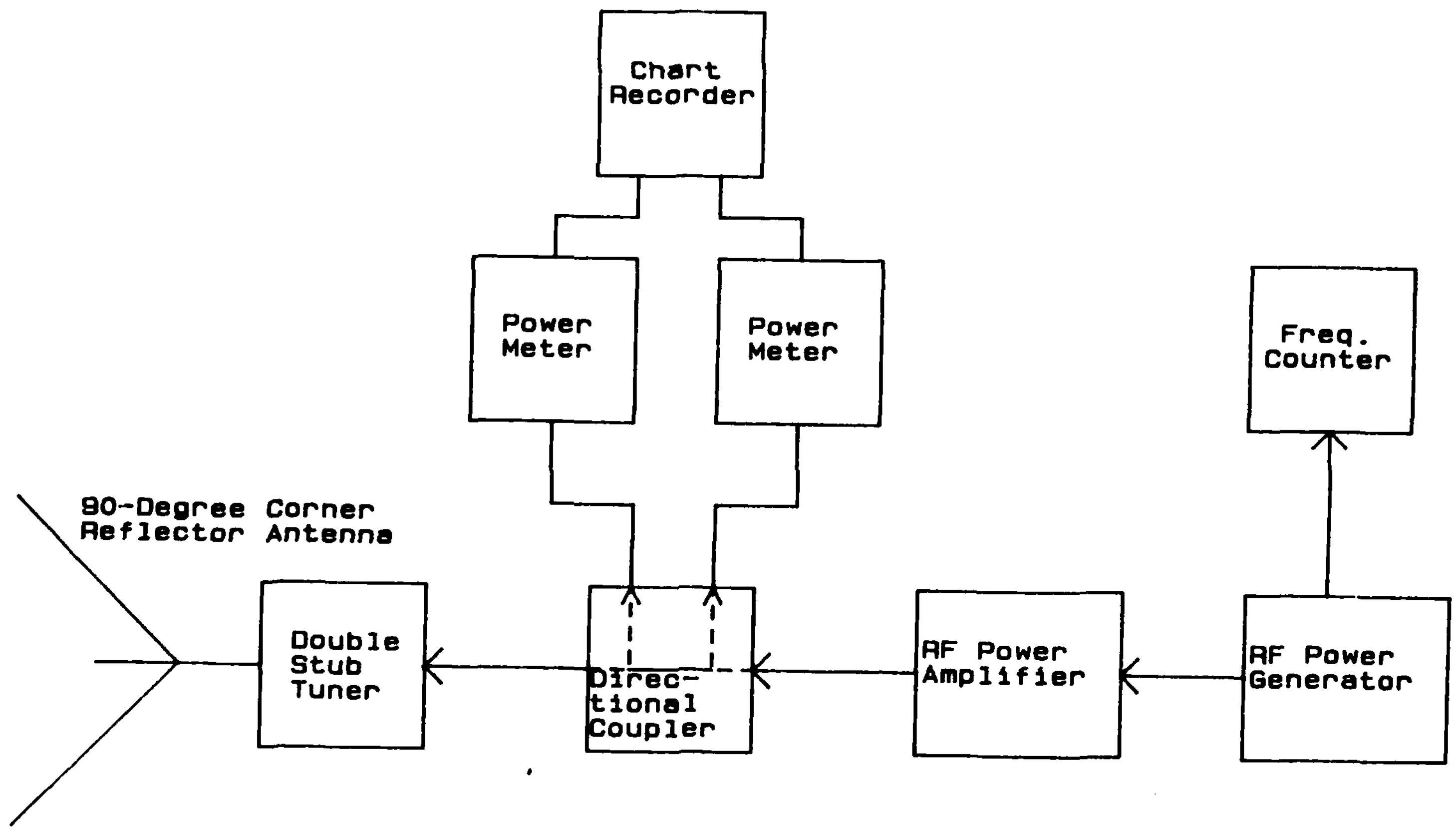

Figure 2. The 700-MHz CW RFR exposure arrangement.

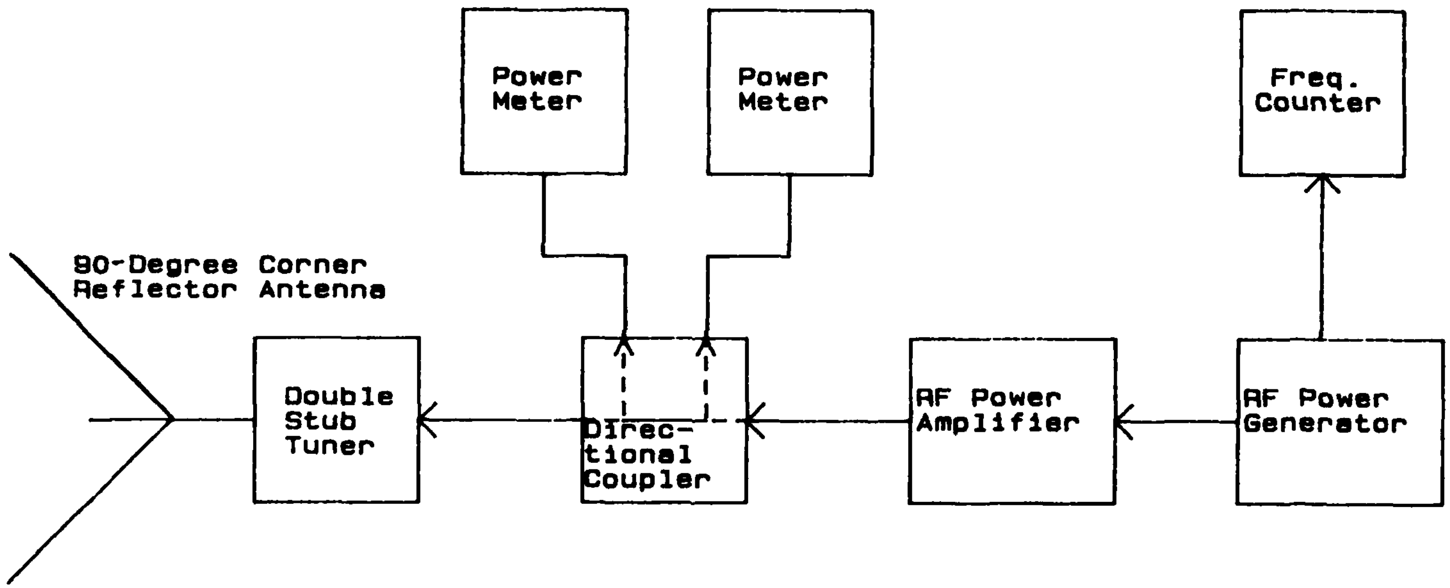

Figure 3. The 350-MHz CW RFR exposure arrangement.

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